Prehospital Data Collection and Analysis for Combat Algorithm Design and Remote Triage[1]

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ABSTRACT

Few data warehousing systems provide a complete and continuous history of trauma patients from the outset of prehospital care to the point of hospital discharge. Typical prehospital database systems are limited to data recorded by emergency personnel during patient transport and contain a minimal number of data points. This incomplete information provides a snapshot of patient status during the course of treatment, but does not present a complete picture. Furthermore, the lack of patient outcome information in prehospital trauma data repositories severely limits meaningful correlation analyses. This lack of data has consequently led to the development of treatment algorithms based on anecdotal evidence rather than proven statistical methodologies. Therefore, in order to develop more accurate prehospital protocols and algorithms for remote triage, we created a robust system for recording patient injuries, vital signs, interventions, and outcome. This paper describes the Trauma Vitals warehousing system which was designed to provide researchers with a comprehensive database for the continuous capture, storage and analysis of trauma patient data during all phases of prehospital and hospital critical care. Patient prehospital vital signs are recorded automatically to ensure comprehensive data collection. Automatically collected prehospital data is combined with manually entered prehospital and emergency department (ED) hospital data. The system incorporates a web-based approach using a Java applet interface for handling user requests and data management commands to an underlying real time database.

1.0 INTRODUCTION

Prehospital treatment of trauma patients is a critical aspect of emergency medical practice in both civilian and battlefield environments. Initiation of early and effective life saving interventions (LSIs) after severe trauma injuries directly affect patient morbidity and mortality rates. Historically, due to a lack of prehospital critical information, such as fluctuations in patient vital signs during transport, treatment decisions have relied on the experience of medical personnel, not on empirical data. Typical physiological monitoring of injured patients involves a single data point (one blood pressure, pulse, respiratory rate and mental status) or at best two such measurements during the prehospital care phase. This severely restricted and often imprecise physiological information serves as the basis for critical decisions regarding appropriate interventions. However, in order to effectively develop new emergency protocols and treatments or to validate current procedures a statistically

[1] The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the Department of the Army or the Department of Defense.

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valid model is needed. Design of an automated prehospital data collection system is a critical step for future critical care options. Such a system will provide tools for making triage decisions for multiple patients in the field. Combined with patient outcome (dead or alive) information, accurate trauma injury models can be designed to more effectively prioritize patients and create a better patient flow to the different available facilities.

In the past, database technologies for capturing disparate patient information from multiple heterogeneous sources have taken several approaches based on a basic relational model [1-5]. However, these approaches do not address high resolution vital signs recorded from patient monitoring devices and do not cover the entire critical care phase that is required for effective analysis of trauma patients. The U.S. Army Institute of Surgical Research, in collaboration with the University of Texas Health Science Center in Houston, TX, has developed the Trauma Vitals system for the capture and analysis of prehospital patient vitals signs and to address the lack of prehospital trauma data available to researchers. This unique system permits warehousing of patient prehospital and hospital information, treatments and outcomes for use in the verification and validation of trauma injury models. The system has the capability to automatically record real time numeric as well as waveform data from Code 3 (severely injured) trauma patients during the prehospital transport phase. Using a web-enabled client, (a Java program downloaded to a local computer), a research nurse can create a patient record that includes a complete representation of a patient's physiological status during the prehospital phase in addition to ED treatments, and eventual patient outcome. Similarly, using a web-enabled client, researchers can query the system for particular data sets which can be imported into statistical analysis packages.

The Trauma Vitals system is currently operating in the Houston Life Flight service to record trauma patient information from Code 3 helicopter transports in the Houston metropolitan area to the Level 1 trauma center at the Memorial Hermann Hospital. The system already contains data for more than 850 patients available for analysis through a web-enabled front end client and is expected to grow significantly as additional data collection sites are added at other Level 1 centers.

2.0 SYSTEM OVERVIEW

The Trauma Vitals system is composed of two modules that work symbiotically to provide patient prehospital and ER data storage capability. An automated data recording module records prehospital vital signs en route to the critical care facility. The second module consists of a web-enabled warehousing system designed for use by trauma researchers and patient data managers. Data from all recorded incidents is stored and correlated using a relational database engine that provides the data management tools for storage and warehousing the records in addition to providing the querying engine for data analysis and algorithm testing.

- The system was designed with the following characteristics in mind:
- Web-based client data management and querying design to provide ubiquitous access capabilities.
- Relational database and warehouse server technology to enable high performance and availability implementation of the underlying data warehouse.
- Standards-based formats and communication protocols; XML data representations and formats supply seamless information exchange and exporting from the system.

3.0 AUTOMATED DATA CAPTURE AND PROCESSING

The data recording system includes the capture of data from multiple simultaneous sources through the use of an automated data recording system. The system consists of a personal digital assistant (PDA) attached to a Propaq model 206EL vital signs monitor via a serial RS-232 cable. Each unit is deployed on every emergency vehicle involved in patient transports to the receiving hospital. The collected data is stored in a removable storage card loaded onto the PDA through a built in expansion slot. Figure 1a shows the Propaq monitor with the original PDA used for the project. Initial deployment of the data collection unit was done using the commercially available HP Jornada PDA. However, due to reliability issues, this unit was subsequently replaced by a rugged device from the Talla-Tech corporation. Figure 1(b) shows the new PDA (Tacter R-PDA, Talla-Tech, Inc., Tallahassee, FL) used by the collection unit.

(a) Original Propaq monitor and PDA data collection unit

(b) upgraded rugged PDA

Figure 1

Collection of prehospital data requires a system capable of capturing patient data during transport from the incident scene to the receiving hospital. Monitors are placed on the patient during transport for evaluation of conditions as dictated by the emergency protocols of the responding emergency personnel. Collection of this data, therefore, has to be implemented such a manner as not to interfere with the normal duties of EMS personnel. Transparency of the data collection process has been a major objective in the implementation of the system.

The Tacter R-PDA Type B data collection unit uses a custom-built RS-232 cable for interfacing between the rugged connector on the PDA and the RS-232 Acuity port on the Propaq monitor. Communication between the PDA and the device is done through the PDA serial port using proprietary software written for the PocketPC operating system based on the Microsoft Embedded Visual tools development environment. This software module implements the required device management functions for activating the data collection sessions, saving and retrieving recorded streams, and managing stream inputs from the monitor.

The data capture unit had several operational requirements which needed to be met before deployment:

- *Transparent operation*. The data collection system had to operate without interfering in the routine operations of emergency personnel. To this end, a software daemon in the PDA monitors the power activity of the Propaq monitors continuously. Using a cyclic packet, the daemon interrogates the communications port of the monitor using a status packet. During power-off phases, the monitor does respond and the PDA is kept in sleep mode. If an acknowledgement is received by the PDA in response to the status packet, the PDA is set to capture mode and a new patient record is created. In this manner, all activities of the monitor are managed by the PDA transparently from the emergency personnel.
- *Text-based storage of recorded vital signs*. In order to verify the quality of recorded data packets, an ASCII (text) based format was developed to store the data streams generated by the monitor. Using a text format simplifies the verification and validation of captured data without requiring specific reader/writer tools to accommodate the chosen file format.
- *Extended data capture capability*. Units in the field require a data storage and battery capacity of at least 48 hours to accommodate weekend shifts. This necessitated storage and battery capacity for recording all required vital signs during these extended deployment shifts. Memory requirements were met by using a PCMCIA card with a 32 MB storage capacity that allows continuous recording time of approximately 5 hours. The battery life of the device was extended by using two power saving daemons to conserve the software power usage during operation. A screen manager daemon implements a screen blanking algorithm for turning off power to the screen when not in use. Similarly, a file manager daemon is used to transfer data files to the local storage card only during file closing procedures. These measures enable the data collection unit to operate up to 72 hours unattended.
- *Required numeric vital signs (from monitor)*

  a. Heart Rate (from echocardiogram (ECG), oxyhemoglobin saturation (SpO2), and non-invasive blood pressure (NIBP)

  b. NIBP (Systolic, Diastolic, Mean)

  c. SpO2

  d. End tidal carbon dioxide (EtCO2)

  e. Respiration rate
- *Required waveform vital signs (from monitor)*

  a. ECG

  b. SpO2

  c. Respiration

The collected data is uploaded to a centralized SQL-based server via a web-enabled Java client application by a project research nurse. Data stored in the server includes the recorded vital signs along with the written patient run sheet, chart information, and eventual patient outcome. Communication protocols and data exchange transactions are handled by a server side Java module which manages communications between the Java clients and the underlying database system.

4.0 WEB ENABLED DATA MANAGEMENT

In order to create a complete record of the trauma patient, data is collected from all critical care treatment phases. This includes obtaining data for treatments, diagnosis, status, and medications given during the transport phase and during the ED visit. Additionally, the patient outcome is also obtained as part of the incident record. Treatment and diagnosis data is divided into the prehospital and hospital (ED) phases. Prehospital data includes:

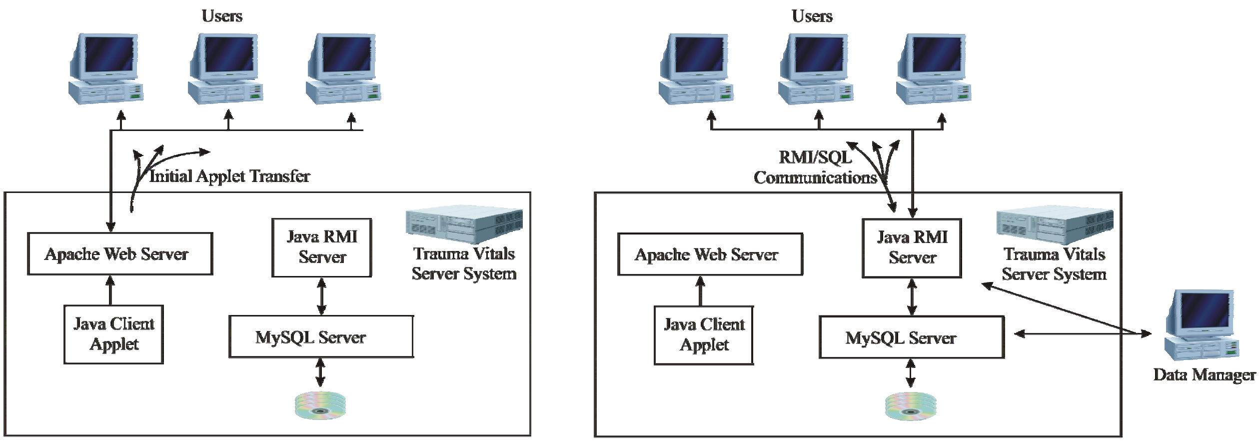
- Incident description. Estimated time of incident and additional scene times as an offset of the time of incident. No dates, names, or other identifying information is included due to HIPAA restrictions.
- Prehospital interventions. All interventions performed by emergency personnel, entered manually via the client interface.
- Manual pulse characters for the radial, femoral, and carotid arteries.
- Patient injuries and method of injury. Recorded manually by paramedics.
- Fluids given. Fluid types and volume.
- Glasgow Coma Score at the incident scene.
- Manual respiration rates and blood pressures. Taken directly by emergency personnel.
- Automatic numeric and waveform vital signs.
- Hospital data recorded by the system:
- Hospital interventions. All interventions performed in the ED after arrival.
- Diagnosis and Treatments. ICD9 codes for the treatments and diagnosis in the ED.
- Fluids. Fluids given in the ED in the first 24 hours.

Other data :

- Post 24 fluids. Fluids given after the first day of treatment.
- Patient outcome. Alive or dead at discharge with corresponding time.

In order to facilitate the storage of all these disparate sets of data items, a client/server system is used to correlate and manage both automatic and manually collected data sets. The system client is deployed via a Java applet which is deployed on a web site which users visit to log into the system. The applet uses a Java interface to allow the users to manage the current set of data, upload new records to the system, or query the system for patterns of interest.

Communication between the client and the database server is implemented in a two-phase approach. Phase 1 consists of a user login into a web page containing the client Java applet needed by the system. An Apache web server is used to deploy the content of the web page in addition to sending the client applet up to the requesting user via the standard HTTP web protocol. Figure 2(a) shows the communication path for the initial client download. The client applet is contained within a signed Java Archive (JAR) file that the user must accept through the standard web security protocol in order for the application to execute on the user's machine. Once the applet has been fully downloaded and accepted by the user, the Java Run Time (JRE) environment on the client machine will execute the applet code to initialize and establish the second phase connection back to the database server. Using a standard Remote Method Invocation (RMI) protocol, the client applet will establish a connection to an RMI server process on the database machine. Database access commands are executed by wrapping the client SQL commands with RMI procedure calls. Calls to the system meet the current standard SQL format [6]. The RMI server attaches to the underlying database and data repository using a standard JDBC driver. Figure 2(b) shows the send phase connection between the client and the RMI server. Arriving RMI procedure calls are converted to SQL commands by the RMI server and executed on the attached database. Results are returned via RMI string packets. The system currently uses the MySQL database engine for maintaining the data repository. Figures 3(a) and (b) show some sample screenshots from the client application.



(a) Initial client applet deployment **(b) Established communication pattern**

Figure 2

Use and administration of the system is governed by a set of operational levels which define the role of each user who has access to the system. These include read only access, read/write access, and administration. Read only access users can query the system and observe results, but cannot create new records. Similarly, read/write access is given to data managers who will collect the needed data and upload it to the system as new records. Finally, an administrator level is used for managing system resources and accounts.

5.0 ONLINE QUERYING SYSTEM

Once a patient record has been loaded and verified by the system data managers, the record becomes part of the data warehouse and is available for queries by system users. These queries are performed by the users through the use of selection and range operators which allow researchers to query every data item on the incident record. Several approaches have been developed to effectively query and retrieve medical records from a relational database or develop new querying languages specific to medical record requirements [7-14].

Elements which are either present or absent from the incident record are queried through a selection operator using a drop down approach for each item on the system. For example, if a patient was intubated in the prehospital phase, then the user can select the intubation intervention from a pull down list and add it to the query. If a single item is added to the list, all records which have the item present will be retrieved by the system. Range operators are used for selection of data items which have numeric ranges. Items can be queried based on less than (<), greater than (>), equal to (=), or in between (< x <). Multiple selections within a particular data item (such as prehospital LSI) are chained as OR queries, whereas multiple selections across different data items (such as prehospital LSI and prehospital NIBP) are treated as AND queries. Items stored as free text (such as descriptions) can be queried using a "*" operator for matching one or more text patterns in the field.

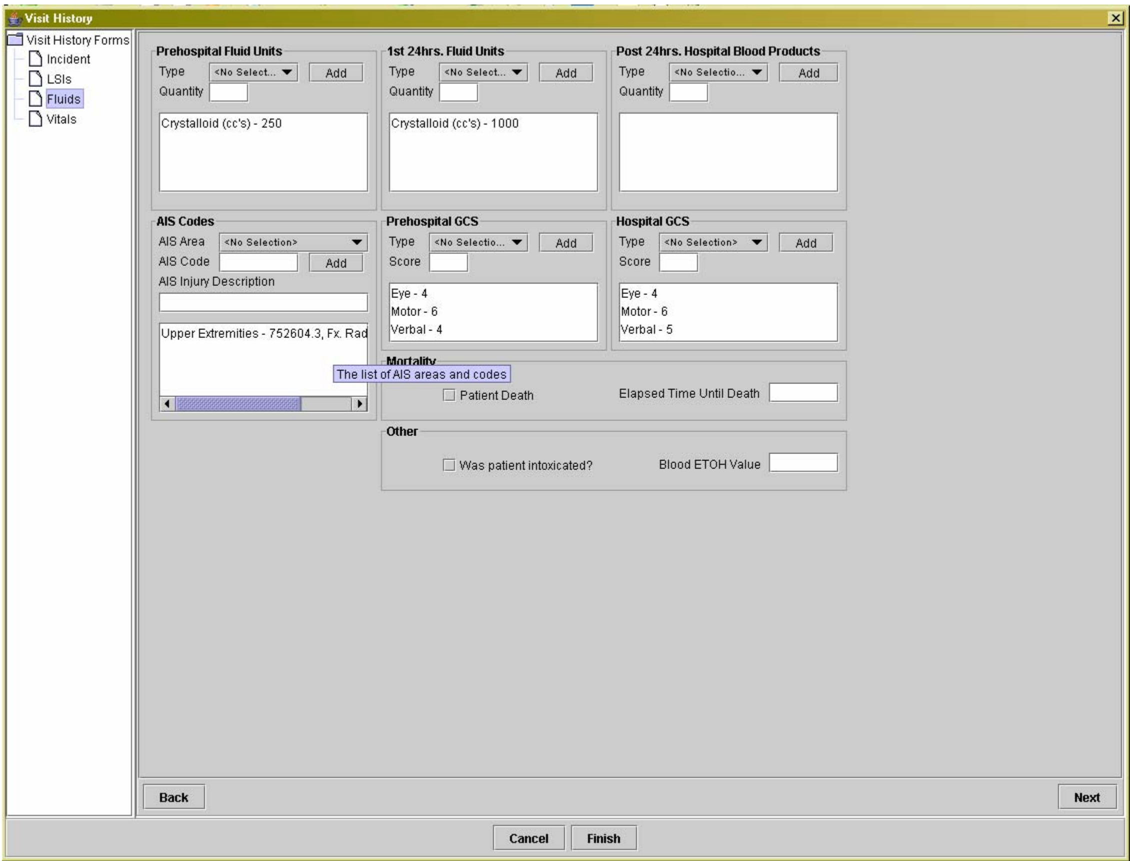


Figure 3a: Example screenshot of fluids page

Query results are returned to the user as a list of patient records that match the query inputs. Figure 4 shows an example query results page. Query results can be further limited by selecting/unselecting individual patient records from the results page. The remaining selected records can then be exported to the local user's computer for further analysis and validation.

Query records can be exported in both XML and character delimited formats. Due to the possible large sizes of the associated captured vital signs, the user has the ability to select if captured data streams should be exported to the local machine with the rest of the records. This format is useful for exchanging data files between systems by creating a self describing file format which can easily be exchanged across heterogeneous systems [15-17]. A character delimited file export can generate the selected records as a text file which can be imported into commercially available data tools.

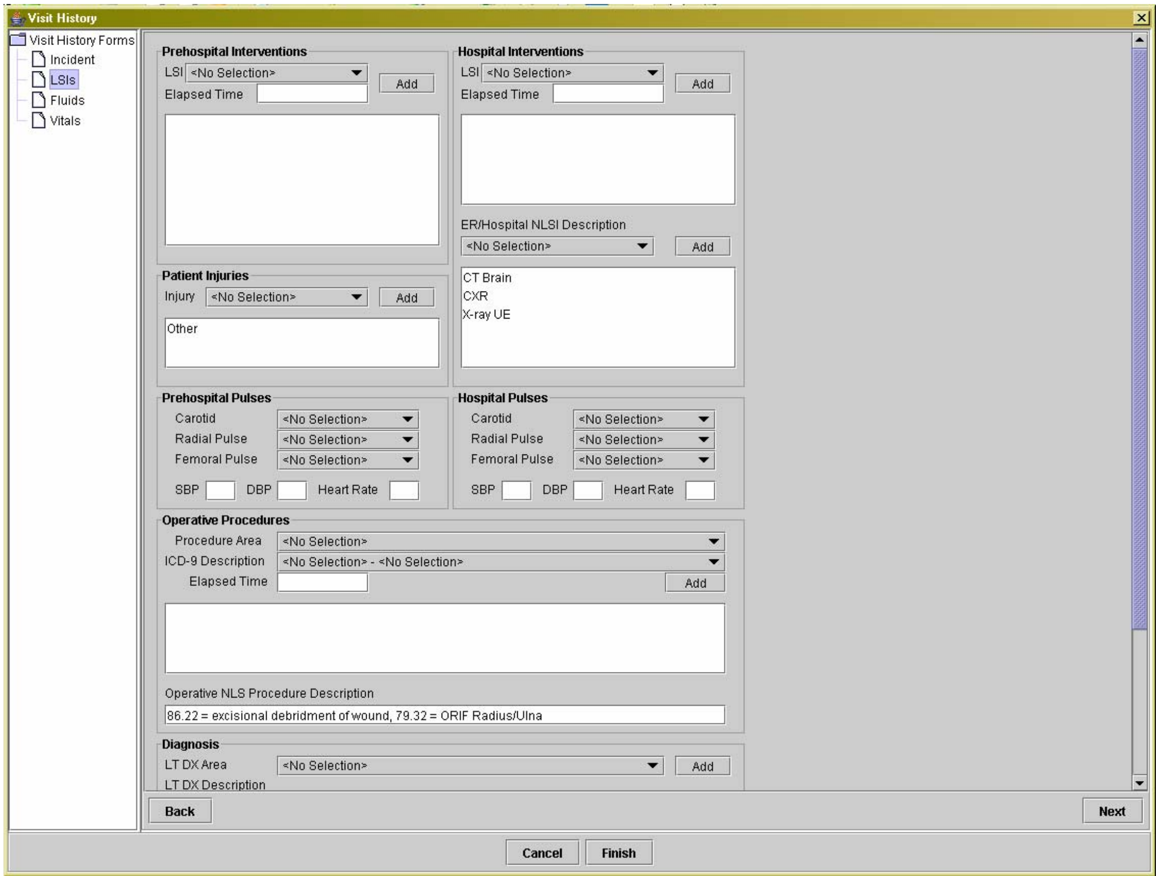


Figure 3b: Example screenshot of LSI page

6.0 CURRENT STATUS

The Trauma Vitals system is in use at the Memorial Hermann Hospital Life Flight system in Houston, Texas. The Life Flight service has three helicopter transport vehicles for the Houston metropolitan and surrounding areas and averages 10 trauma patient transports per day. All helicopters in the service have been deployed with a data collection unit for complete coverage of all helicopter critical patient transports. A full time research nurse manages the data collection and uploading of patients to the database from his/her workstation. The current system contains over 850 fully correlated incident records with prehospital, hospital, and outcome data.

7.0 FUTURE DIRECTIONS

Future directions will concentrate on improvement of the data collection process, expansion of the data collection sites, better data management approaches, and improved data warehousing functionality. The current system has been limited to capturing data streams from a Propaq monitor through a PDA. However, we are testing new air-certified monitors that can collect data using internal and/or removable storage devices, for possible replacement of the current system. Work will also focus on expansion of the data collection project beyond the current deployment in Houston, TX. The addition of new data collection sites will provide larger population samples and create a more statistically robust data representation for trauma and critical care patients.

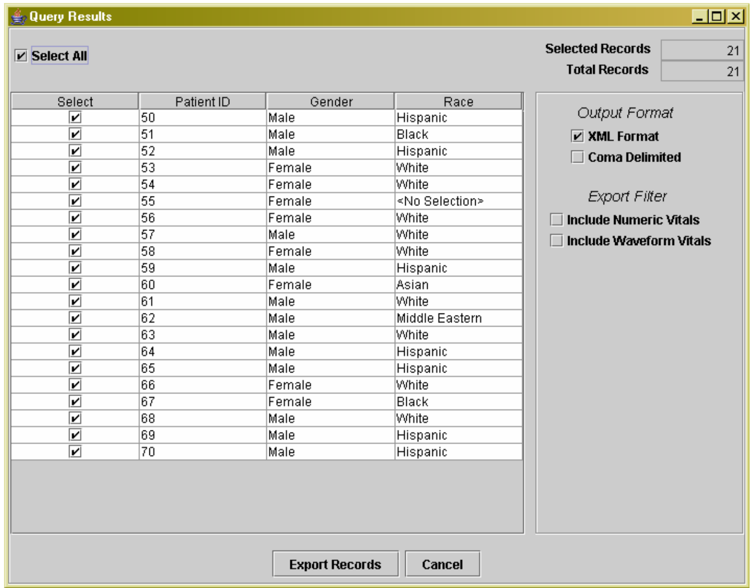


Figure 4: Example query results screen

Currently, the warehousing system is implemented using a MySQL database backend server. A new schema has been designed to accommodate additional database servers including Oracle and SQL Server. These new architectures will improve database capabilities for expansion of the system as new data collection sites are created. A new schema has been designed for more accurate tracking of records, and to provide increased performance for users through new Java and web-enabled technologies.

8.0 SUMMARY

The Trauma Vitals system has been designed to provide a means for collection, storage, and analysis of prehospital and emergency patient data. Using a set of automated data recording units, the system is able to capture a patient's real time vital signs from the time of incident pickup until hospital delivery. When combined with the manually digitized incident information and patient outcome, the system is able to provide a complete picture of the critical care patient.

Using web-enabled techniques, the system provides an online accessible warehouse of critical care variables which can be used by researchers for verification and validation of current and future emergency and prehospital protocols. The system is built using standard commercial off-the-shelf database and client/server software components to provide a system which can be accessed via any standard HTML and Java compliant browser. Using client/server communication techniques between a Java applet executing on the client machine and the centralized server system, users and administrators can manage all stored patient records and provide a means for querying patient records on any prehospital or ER item warehoused by the system.

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